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Synthesis, Structure and Properties of BN Nanotubes, BN/SiC and CBN/SiC Micro/Nano-Whiskers

CRDF COOPERATIVE GRANTS PROGRAM: FINAL PROJECT REPORT

SECTION I: Public Summary

Award Number: UE2-2456

1) Brief statement of project's major accomplishment

- 1. Development of experimental carbothermal technology for fabrication of BN/SiC tube-whiskers and BNC/SiC nano-hetero-cable.**
- 2. Theoretical substantiation of their application in kind of acousto-electronic ultrasound transducer for hypersound generation in extremely high-frequency range 1GHz-1THz.**
- 3. Synthesis of novel unconventional zeolite-like polymorph on base of BN.**
- 4. Prediction of new physical effect, namely, photo-acousto-electronic super-resonance in nanotubes and nanotubular crystal.**

2) Public Summary (English)

The original goal of the project was synthesis and characterization of BN nanotubes, BN/SiC and CBN/SiC micro-nano-whiskers.

In the result variety of BN nanostructures have been synthesized by carbothermal technique and characterized by TEM and EPR, SPR and Raman spectroscopy, including:

- pure multi-wall BN nanotubes and onions;
- BN/SiC tube-whiskers, that are SiC whiskers of 0.2 - 0.8 mk in diameter and 60 - 120 mk in length covered by tubular BN sheet of ~10 nm thick;
- BNC/SiC hetero-cables presenting SiC whiskers with C and BN covers.

Their application in kind of acousto-electronic ultrasound transducer for generation of acoustic hypersound waves (phonons) in extremely high-frequency range 1GHz-1THz was substantiated.

In first time novel unconventional polymorphic BN phase named as the hyperdiamond fulborenite was obtained by supercritical fluid synthesis at intermediate pressure and temperature. Structure of novel carbon allotropes and boron nitride polymorphs were designed and their electronic properties have been calculated by FLAPW method. Remarkably that bulk module $B=590$ GPa for HDF- $B_{12}N_{12}$ was calculated to be greater then for diamond $B=540$ GPa. This novel BN phajausite is expected to become record superhard semiconducting material.

Unique opportunity for combined photo-acousto-electronic super-resonance in nanotubes and nanotubular 2D crystals is predicted theoretically in first time. This novel phenomenon is possible only on some sole frequency named as the "super-resonance frequency", that is novel characteristic inherent to nanotubular crystals. If confirmed this new physical effect will find unprecedented applications.

3) Public Summary (FSU Language)

Метою проекту був синтез і дослідження BN нанотрубок, BN/SiC і CBN/SiC мікро-нано-волокон.

В результаті карботермічним методом було синтезовано і методами ПЕМ, ЕПР, ППР і Раман спектроскопії характеризувано цілий ряд нітрид-борних наноструктур, зокрема:

- чисті багато-стінні BN нанотрубки і оніони;
- BN/SiC тубо-волокна, тобто SiC волокна діаметром 0.2 - 0.8 мк довжиною 60 - 120 мк покриті трубчатим BN оболонкою товщиною ~10 нм;
- BNC/SiC гетеро-кабелі, тобто SiC волокна з C і BN покриттям.

Обґрунтовано їх використання в якості акусто-електронного перетворювача ультразвуку для генерації акустичних гіперзвукових хвиль (фононів) в гранично високочастотному діапазоні 1ГГц - 1ТГц.

Нова нетрадиційна поліморфна BN фаза названа гіпералмазним фулборенітом була отримана методом надкритичного флюїдного синтезу при проміжних температурах і тиску. Спроектвано структуру і методом ПППХ розраховано електронні властивості ряду нових аллотроп вуглецю і поліморф нітриду бора. Чудово що розрахований об'ємний модуль $B=590$ ГПа для одного з них ГАФ- $B_{12}N_{12}$ виявився більшим ніж для алмазу. Цей новий BN фазозит може стати рекордним надтвердим напівпровідниковим матеріалом.

Вперше теоретично передбачена унікальна можливість комбінованого фото-акусто-електронного супер-резонансу в нанотрубках і нанотрубчатих 2D кристалах. Це нове явище можливе тільки на деякій єдиній частоті, названою "супер-резонансною" частотою, що є новою характеристикою притаманною нанотрубчатим кристалом. Якщо цей фізичний ефект підтвердиться то він знайде безпрецедентні застосування.

CRDF COOPERATIVE GRANTS PROGRAM: FINAL PROJECT REPORT

SECTION II: Technical Report Award Number: UE2-2456

Technical Report

The work on the project was developing in the IPMS UASU and Clarkson University.

The report is completed and authorized by both PIs, Profs. Richard Partch and Vladimir Pokropivny.

The research was conducted in all of the following directions:

1. Synthesis of SiC fibers using carbon nanotubes as a template and covering them by BN films.
2. Synthesis of homogeneous h-BN covers on different SiC whiskers.
3. Technology parameters optimization for fabrication of BN/SiC tubewhiskers
4. Characterization and investigation of samples properties by XRD, SEM, TEM, IR, EPR, and Raman spectroscopy.
5. Theoretical and computational research of BN-nanotubes, SiC-nanowires by GAUSSIAN98, and molecular dynamics techniques.
6. Ab-initio calculation of electronic and mechanical properties of the novel unconventional carbon allotropes SCF-C₂₄, and boron nitride polymorphs SCF-B₁₂N₁₂, SCF-B₂₄N₂₄, HDF-B₁₂N₁₂ by FLAPW technique.
7. Synthesis of novel polymorphic modifications of BN, in particular, HDF-B₁₂N₁₂ by supercritical fluid technique.
8. Magnetic properties study of porous silicon powder synthesized by electrochemical technique.

Developments and Accomplishments:

1. BN nanotubes.

Variety of pure BN nanotubes was synthesized by carbothermal method and characterized by SEM, TEM and Raman spectroscopy. This reaction ($B_2O_3 + 3C(NT) + N_2 = 2BN(NT) + 3CO$) was used further as the first stage for covering of SiC substrate and wires. The IR, Raman, EPR, and surface plasmon resonance (SPR) spectra of these samples were obtained. Different kinds of pure BN plates, onions, bamboo-like and straight nanotubes with great yield were obtained (fig.1)



FIG. Electron-microscope images of BN-nanotubes. Bamboo structure (right) and variable diameter cylindrical (left)

Fig.1. Multi-wall BN-nanotubes synthesized by carbothermal technique.

Infra-red and Raman spectra of single-wall BN nanotubes (SW-BNNT) of zig-zag and arm-chair configuration were calculated by PC GAMESS package using both semi-empirical (MNDO,PM3) and ab-initio (HF, DFT, MP2) methods. Calibration procedure was introduced to feet calculated and experimental Raman spectra, especially intensive peak of 1366 cm^{-1} , of referenced small h-BN sheet. Raman spectra of SW-BN-NTs was shown to depend on their diameter in contrast to IR spectra. The frequency in range $1160\text{-}1366\text{ cm}^{-1}$ was concluded to be responsible for the diameter distribution of BN-NTs in experimental samples. Main tangential mode 880 cm^{-1} was found to be the main distinguishing feature of BN-NTs. Good agreement between calculated and experimental Raman spectra for low-frequency breathing modes able us to conclude that calculated spectra of BN-NTs of different chirality, diameter and thick can be used to resolve the experimental spectra as well as to determine contents of the samples.

2. BN/SiC tube-whiskers and BNC/SiC nano-hetero-cables.

Series of experiments were performed to process optimize for covering of SiC whiskers by thin BN sheet, using two kinds of precursors and two kinds of SiC whiskers. Our IPMS's SiC-whiskers was characterized to be of $0.2 - 0.8\text{ mk}$ in diameter, $60 - 120\text{ mk}$ in length, and have the $8.1\text{ m}^2/\text{g}$ specific area, while the USA's SiC-whiskers was observed to be thicker and shorter in several time having smaller specific area $2.4\text{ m}^2/\text{g}$.

In first experiments series using IPMS technology precursors the SiC whiskers wetted by spirits were mixed with saccharine (the carbon source) of different concentration and were processed in magnetic stirring rod during 30 minutes. Then the mixture was drying and carbonized by pyrolysis in argon flow by graduated heating. The samples were mixed in $\text{Li}_2\text{B}_4\text{O}_7$ and nitrogenized a) in nitrogen flow at 1300°C during 3 hours; and b) in ammonia flow at 1100°C during 1 hour. The samples were characterized by SEM, TEM, and Raman spectroscopy. On both kinds of SiC whiskers a number of thin entire compact homogeneous covers of $\sim 20\text{ nm}$ in thick have been fabricated.

In second experiments series using R.Partch's technology a polyvinil-acetate was used as the precursor instead of sacharase. TEM observation shows the BN covering sheets in first series more homogeneous then in the second one.

TEM images and Raman spectra (fig.2) show the presence of relatively thin ($\sim 20\text{ nm}$) homogeneous BN-sheets on SiC whiskers of $200\text{-}800\text{ nm}$ in diameter.

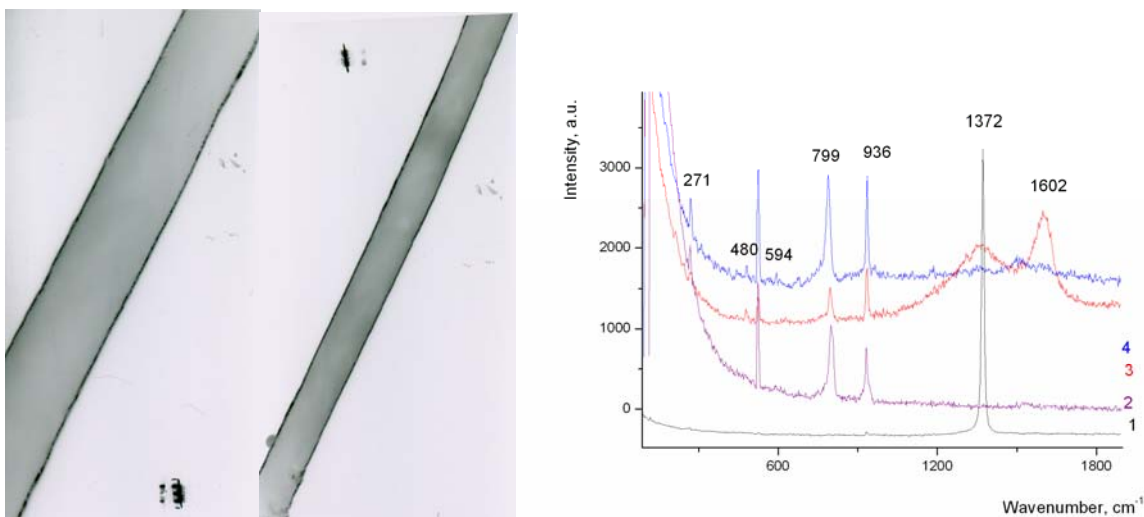


Fig.2. TEM images of BN/SiC tube-whiskers and their Raman spectra (1 - turbostratic BN, 2 – SiC whiskers, 3 – BN/SiC tube-whiskers synthesized by CAMP technology; 4 - BN/SiC tube-whiskers synthesized by IPMS technology).

3. Configuration of hypersound transducer on base of BN/SiC tube-whiskers.

Novel innovative idea was proposed to design a hypersound transducer in extremely high-frequency range on base of heteropolar-tube-whiskers (HTW) for instance BN/SiC-TW and their arrays. In contrast to nanorodes and plates in the nanotubes the peculiar gallery of whispering acoustic modes (breathing A_{1g} , squash E_{2g} , et al.) is possible to propagate due to its cylindrical form. An inherent important feature of these vibrations is their weak attenuation. The frequencies of this gallery depend on the diameter d and they may be estimated as $f=v/l \sim v/d \sim 3\text{km/sec} / 10\text{nm} = 300 \text{ GHz}$. For $d=3\text{nm}$ $f \sim 1\text{THz}$. In addition piezoeffect is possible in BN heteropolar NTs. Hence these nanotubes give the base for effective generation of extremely high-frequency acoustic hypersound vibrations from Giga to Tera- Hertz range. BN/SiC HTW special in size, in diameter and in orientation are requested that is not obtained to this time. Principal scheme of this hypersound device is shown in fig.4.

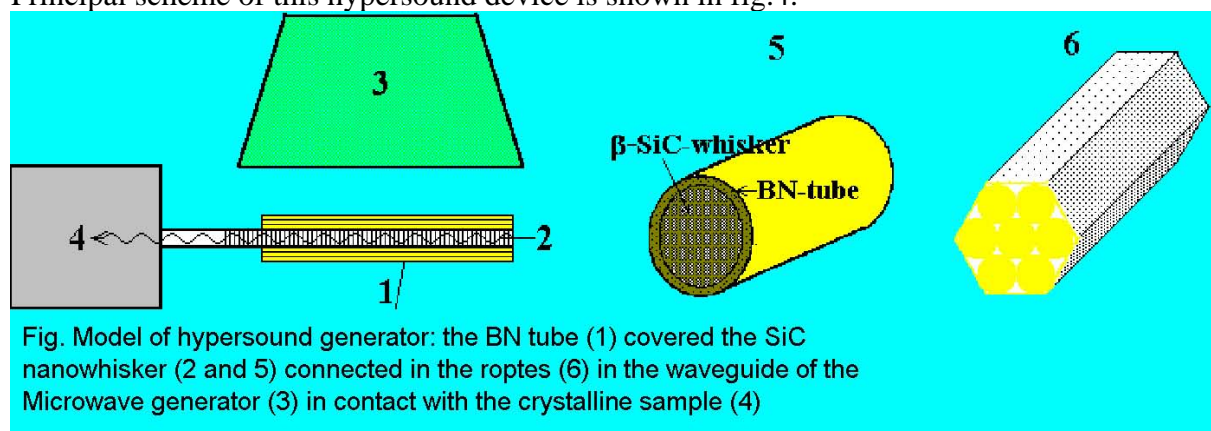


Fig. Model of hypersound generator: the BN tube (1) covered the SiC nanowhisker (2 and 5) connected in the roptes (6) in the waveguide of the Microwave generator (3) in contact with the crystalline sample (4)

4. Novel allotropes of carbon and polymorphes of BN.

Novel boron nitride faujasite-like polymorph HDF-B₁₂N₁₂ was theoretically calculated, synthesized by supercritical fluid method, and experimentally examined.

Great achievement of the project is the synthesis of novel polymorphic modification of boron nitride named as the hyperdiamond fulborenite HDF-B₁₂N₁₂ known previously as E-phase by supercritical fluid synthesis using gazostat equipment at intermediate pressure ($P < 300 \text{ MPa}$) and temperature ($T < 1000^\circ \text{C}$) in different atmospheres. Its structure is the hyperdiamond fullerite lattice built from molecules B₁₂N₁₂ (HDF-B₁₂N₁₂) with lattice parameter $A = 1.152 \text{ nm}$ and density $\rho = 2.59 \text{ g/cm}^3$. The XRD and IR spectra are in good agreement with literature data. The samples were further characterized and investigated by SEM, TEM, XRD, IR, Raman, EPR technique confirming the presence of novel polymorph.

In first time energy band structure, the equation of states, the densities of electronic states, and the electronic density map of novel carbon allotropes and BN-polymorphs have been calculated by *ab-initio* FLAPW method (fig.5).

Electronic structure of simple cubic fullerites SCF-C₂₄ and fulborenite SCF-B₁₂N₁₂ (fig.3.2) have been calculated. Equilibrium interatomic distance $a_{\text{CC}} = 0.1550 \text{ nm}$ and $a_{\text{BN}} = 0.1537 \text{ nm}$ is intermediate between diamond (sphalerite BN) and graphite (h-BN). The SCF-C₂₄ was shown to be a diamond-like molecular dielectric or semiconductor with 1.6 eV band gap. This is novel carbon zeolite combining the generous porosity and nonpolarisability with high mechanical properties (bulk module $B = 196 \text{ GPa}$, elastic moduli $C_{11} = 338 \text{ GPa}$, $C_{12} = 139 \text{ GPa}$, $C_{44} = 30 \text{ GPa}$), chemical inertness, and high thermal conductivity. All of these point on SCF-C₂₄ as perspective low-dielectric material ($\epsilon < 5.7$) for inter-connectors and substrates for integrated circuits. The SCF-B₁₂N₁₂ was shown to be the diamond-like molecular semimetal with 0.1 eV band gap.

Structure of fulborenite SCF-B₂₄N₂₄ is shown in fig.5.1. Its building units clusters B₂₄N₂₄ have been discovered recently in mass-spectra of arc-melting BN. Calculated parameters are: the equilibrium lattice parameter $A = 0.73458 \text{ nm}$, length of B-N bond $a_{\text{BN}} = 0.1521 \text{ nm}$, number of atoms per unit cell $Z = 48$, density $\rho = 2.495 \text{ g/sm}^3$, bulk module $B_0 = 367 \text{ GPa}$, band gap $\Delta E_g = 3.76 \text{ eV}$. It was concluded to be the heteropolar superhard semiconductor or dielectric.

Electronic structure of hyperdiamond fulborenite HDF-B₁₂N₁₂ (fig.5.3) was calculated. Bulk module of HDF-B₁₂N₁₂ calculated preliminary without optimization is $B = 590 \text{ GPa}$, greater then for diamond ($B = 540 \text{ GPa}$). This is novel superhard boron nitride faujasite-type semiconductor.

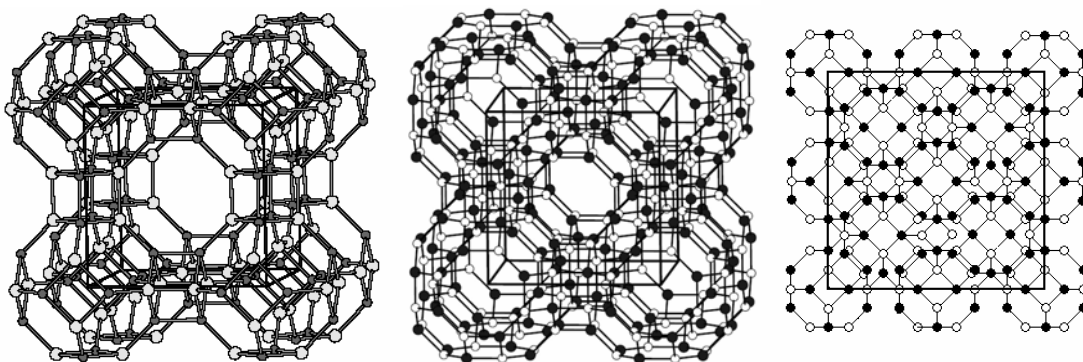


Fig. 5. Elementary cells of the simple cubic fulborenites SCF- B₁₂N₁₂ in which molecules B₁₂N₁₂ are covalently bonded by square faces, the SCF-B₂₄N₂₄ in which molecules B₂₄N₂₄ are covalently bonded by octahedral faces, and hyperdiamond fulborenite HDF-B₁₂N₁₂ with molecules B₁₂N₁₂ copolymerized by hexagonal faces.

5. Porous silicon.

Porous silicon powder was synthesized by electrochemical technique. Magnetic susceptibility and electron paramagnetic resonance spectrum ($g=2.0055$) were measured. In comparison with diamagnetic bulk Si ($\chi_d=-2.29 \cdot 10^{-7} \text{ sm}^3/\text{g}$) the porous Si powder exhibits paramagnetic properties ($\chi_p=1.1 \cdot 10^{-5} \text{ sm}^3/\text{g}$) with weak share of ferromagnetism ($\chi_f=1.85 \cdot 10^{-5} \text{ sm}^3/\text{g}$). The porous-Si is planned to be used as the substrate for further BN covering.

7. Unique opportunity for triple combined photo-acousto-electronic super-resonance in nanotubes and nanotubular 2D crystals is predicted theoretically in first time. This novel phenomenon is possible only on the some single frequency named here as "super-resonance frequency". It is a novel characteristic of matter inherent to nanotubular crystals.

6. New physical effect predicted.

System analyzing size, resonance effects in nanotubes by superposing spectrum of electromagnetic, acoustic, matter waves an unique opportunity for combined photo-acousto-electronic (P-A-E) super-resonance in nanotubes and nanotubular 2D crystals is predicted theoretically in first time on some sole frequency named as the "super-resonance frequency". Combined scale of the acoustic, electromagnetic and electronic waves superposed nearly in frequencies is presented in first time. While diminishing a diameter of nanotube made of superconducting substance a quantum size effect was assumed to arose inevitably leading to a resonance enhancement of electron-phonon interaction that manifest itself in the appearance of superconducting state. Moreover under interaction with electromagnetic waves on this super-frequency a photo-acoustic, a photo-electronic, and a triple combined photo-acousto-electronic super-resonance might be arose in the result. This super-resonance frequency is novel characteristic inherent for nanotubes and nanotubular crystals. It is determined by unique combination of number of parameters, namely, the nanotube material, the type and size of nanotube, the type and parameters of nanotubular crystal, the strength of external magnetic field and frequency of electromagnetic field. Such a state is a novel unique structural state of matter in which a high-effective transformation and pump each other of all three kinds of vibration energy (electronic, photonic, phononic) is possible. Super-resonance may be used for development of a room- T_c superconductor, a hypersound transducer, a phonon quantum generator (phaser), a high-quality nanoantenna, a low-barrier emitter, a high-efficient solar cell.

The main accomplishment of the project is the experimental technology for fabrication of BN/SiC tube-whiskers and theoretical substantiation of their application in kind of acousto-electronic ultrasound transducer for generation of acoustic hypersound (phonons) in extremely high-frequency range 1GHz-1THz.

In addition:

- novel unconventional zeolite-like polymorph on base of BN was observed;
- new physical effect, namely, photo-acousto-electronic super-resonance in nanotubes and nanotube crystal was in first time suggested and theoretically substantiated

CRDF COOPERATIVE GRANTS PROGRAM: FINAL PROJECT REPORT

SECTION III: FSU Team Data
(to be completed by the FSU Principal Investigator only)

Award Number:

A. Research Information

1. Scientific Results

- a. Were the scientific and technical objectives of your original proposal accomplished?
Yes ☐ No ☒

The specific research objectives changed. ☐

b. If specific research objectives were *not* accomplished, please briefly describe the factors that impeded their successful completion (e.g., unanticipated research results, difficulty in communications, administrative or financial complications, etc.).

c. If specific research objectives *changed*, please describe:

d. Please indicate the type of accomplishments achieved under your project (please check all that apply):

- ☒ New theoretical results
- ☒ Elaboration of known topic
- ☒ New experimental results
- ☒ New techniques developed or techniques improved
- ☒ Development of "know-how"
- ☐ Prototype development
- ☐ Patent Application
 - ☐ Pending
 - ☐ Received
- ☒ Publication of results in journal
- ☐ Other (please describe)

2. Collaborative Benefits

a. Describe the benefits of having conducted your research in collaboration with U.S. counterparts rather than independently.

- | | |
|--|---|
| <input checked="" type="checkbox"/> Exchange of ideas | <input checked="" type="checkbox"/> Complementary expertise in particular research area |
| <input type="checkbox"/> Access to new facilities | <input type="checkbox"/> Access to new or previously unavailable information |
| <input checked="" type="checkbox"/> Joint publications | <input type="checkbox"/> Access to new geographical research area |
| <input checked="" type="checkbox"/> Access to new research methods | <input type="checkbox"/> Educational effect on young researchers/students |
| <input type="checkbox"/> Other (please describe) | |

b. Describe any difficulties related to the collaborative nature of the effort.

- | | |
|---|--|
| <input type="checkbox"/> Language barriers | <input type="checkbox"/> E-mail/Internet difficulties |
| <input checked="" type="checkbox"/> Procuring equipment or supplies | <input type="checkbox"/> Paperwork |
| <input type="checkbox"/> Other time commitments | <input type="checkbox"/> Intellectual Property Rights issues |
| <input type="checkbox"/> Travel/Visas | <input type="checkbox"/> Financial Issues |
| <input type="checkbox"/> Other (please describe) | |

c. Will the collaboration with the U.S. team continue? Yes ☒ No ☐

d. If "Yes", by which of the following means? (check all that apply)

- | | |
|---|---|
| <input checked="" type="checkbox"/> Future joint publications | <input checked="" type="checkbox"/> New grant proposals |
| <input checked="" type="checkbox"/> Joint patents | <input checked="" type="checkbox"/> Exchange visits |
| <input checked="" type="checkbox"/> E-Mail contact | <input type="checkbox"/> Other (please describe) |

3. Additional Support

a. Have you submitted applications to any funding agencies for support of your collaborative research? Yes ☐ No ☒

b. If "Yes", please indicate which funding agencies you applied to for possible funding (check all that apply).

- | | |
|--|---|
| <input type="checkbox"/> CRDF (Program: _____) | <input type="checkbox"/> ISTC/STCU |
| <input type="checkbox"/> INTAS | <input type="checkbox"/> FSU Government Agency/Ministry |
| <input type="checkbox"/> NATO | <input type="checkbox"/> European Community Sixth Framework Programme |
| <input type="checkbox"/> U.S. Department of Energy (DOE) | <input type="checkbox"/> U.S. Department of Defense |
| <input type="checkbox"/> National Institutes of Health (NIH) (Please specify NIH institute: _____) | |
| <input type="checkbox"/> For-Profit Company (Please identify: _____) | |
| <input type="checkbox"/> Other: | |

c. If you received any funding to continue your collaborative research, please identify the source(s) from which you have received this funding (check all that apply).

- | | |
|--|---|
| <input type="checkbox"/> CRDF (Program: _____) | <input type="checkbox"/> ISTC/STCU |
| <input type="checkbox"/> INTAS | <input type="checkbox"/> FSU Government Agency/Ministry |
| <input type="checkbox"/> NATO | <input type="checkbox"/> European Community Sixth Framework Programme |
| <input type="checkbox"/> U.S. Department of Energy (DOE) | <input type="checkbox"/> U.S. Department of Defense |
| <input type="checkbox"/> National Institutes of Health (NIH) (Please specify NIH institute: _____) | |
| <input type="checkbox"/> For-Profit Company (Please identify: _____) | |
| <input type="checkbox"/> Other: | |

d. In the future, do you plan to apply for support for continuation of your collaborative research? Yes ☒ No ☐

e. If "Yes," please specify which funding source(s) you plan to apply to for support (check all that apply).

- | | |
|--|---|
| <input checked="" type="checkbox"/> CRDF (Program: <u>FSTM</u>) | <input type="checkbox"/> ISTC/STCU |
| <input checked="" type="checkbox"/> INTAS | <input type="checkbox"/> FSU Government Agency/Ministry |
| <input type="checkbox"/> NATO | <input type="checkbox"/> European Community Sixth Framework Programme |
| <input type="checkbox"/> U.S. Department of Energy (DOE) | <input type="checkbox"/> U.S. Department of Defense |
| <input type="checkbox"/> National Institutes of Health (NIH) (Please specify NIH institute: _____) | |
| <input type="checkbox"/> For-Profit Company (Please identify: _____) | |
| <input type="checkbox"/> Other: | |

4. Technology Commercialization

a. Are you pursuing commercial application of your research results? Yes ☒ No ☐

b. If "Yes", please check all that apply:

- | | |
|---|---|
| <input checked="" type="checkbox"/> Planning joint patent application | <input type="checkbox"/> Planning country-specific patent application |
| <input type="checkbox"/> Approved joint patent application | <input type="checkbox"/> Approved country-specific patent application |
| <input checked="" type="checkbox"/> Contract with for-profit company | <input type="checkbox"/> Prototype development |
| <input type="checkbox"/> Marketing | <input type="checkbox"/> Seeking venture capital investment |
| <input type="checkbox"/> Licensing | <input type="checkbox"/> Manufacturing |
| <input type="checkbox"/> Other: (please describe) | |

c. If "Yes," please provide a paragraph with details about the above-checked plans:

a. Negotiations with Boeing and Nanodynamics Companies were carried out for development of hypersound transducer on base of technology developed in the CGP within the next expected FSTM project

5. Transition to Civilian Science

a. Did your project include researchers who were formerly actively engaged in weapons-related research? Yes ☒ No ☐ (if you check No, please skip to Question 6)

b. Did the CRDF research project provide a positive means for engaging and retaining former weapons scientist(s) in civilian science? Yes ☒ No ☐

c. If Yes, please describe:

d. Did any of the former weapons researchers on your team change institutional affiliation or country of residency during this project? Yes ☐ No ☒

e. If Yes, please describe:

f. What percentage of research time did the former weapons researchers spend on civilian research?
100%

6. Research Infrastructure

a. How did you use technological information resources (such as the Internet, e-mail) to support your CGP project? (check all that apply)

- ☒ To obtain data or information
- ☒ To consult with co-investigator by e-mail
- ☒ To consult with other researchers working on the same or related topics by e-mail
- ☒ To identify future research collaborators
- ☐ To identify funding sources
- ☐ To promote/market the results of the research project
- ☐ To help educate student researchers
- ☐ To aid in the submission of additional collaborative research proposals and publications
- ☐ Other (please describe)

b. Over the course of the award, did you or your laboratory/institute develop new linkages (international or in-country) with any of the following in order to carry out the research project? (check all that apply)

- ☐ Academy of Sciences Research institutions
- ☐ Government Research Institutions
- ☒ FSU Universities
- ☐ Other Universities
- ☐ For-Profit Companies

☐ Other (please describe)

c. Please briefly identify and describe the institutional linkages developed (e.g., “developed arrangement to share access to research equipment with XXX Institute”):

Developed arrangement to share access to research equipment with Moscow IREE Institute

d. Over the course of the award, did you have the opportunity to utilize equipment (for project-related purposes) at your U.S. collaborator's institution or other foreign or FSU institutions?

Yes ☐ No ☒

If “Yes”, please describe:

B. Administrative Information

1. Project Personnel

a. List all members of your CGP research team (including those who worked on the project but did not receive individual financial support from CRDF) including name, date of birth, gender, and affiliation (if different from Principal Investigator's institution). Please include and identify students. Please identify as “Former Weapons Researchers” those project participants who were formerly or are currently actively engaged in research at a current or former weapons laboratory or institution. For those researchers only, please indicate the type of defense-related research by using the code list provided in the Appendix.

#	Name/Institutional Affiliation	Date of Birth (MM/DD/YYYY)	Gender [M/F]	Student ?	Former Weapons Researcher ?	Weapons Research Code (see Appendix for code)
1	Pokropivny, V.V.	10/27/49	M	<input type="checkbox"/>	<input checked="" type="checkbox"/>	D1
2	Prilutsky, E.V.	04/29/38	M	<input type="checkbox"/>	<input checked="" type="checkbox"/>	A1
3	Lyashenko, V.I.	02/03/48	F	<input type="checkbox"/>	<input type="checkbox"/>	
4	Pokropivny, A.V.	01/03/72	M	<input type="checkbox"/>	<input type="checkbox"/>	
5	Smolyar, A.S.	05/19/40	M	<input type="checkbox"/>	<input type="checkbox"/>	
6	Oleinik, G.S.	09/10/41	F	<input type="checkbox"/>	<input checked="" type="checkbox"/>	A1
7	Gubanov, V.I.	02/08/46	M	<input type="checkbox"/>	<input type="checkbox"/>	
8	Mokhort, V.A.	04/15/65	M	<input type="checkbox"/>	<input type="checkbox"/>	
9	Poperenko, L.V.	12/02/50	M	<input type="checkbox"/>	<input checked="" type="checkbox"/>	E1
10	Lisenko, A.A.	01/04/42	M	<input type="checkbox"/>	<input type="checkbox"/>	
11	Ogorodnikov, V.V.	12/16/36	M		<input checked="" type="checkbox"/>	D1
12	Bekenev, V.L.	08/26/46	M		<input type="checkbox"/>	
13	Rozhenko, N.M.	06/22/65	F			
14	Brodivoy Alex	12/11/53	M		<input checked="" type="checkbox"/>	A1
15	Storchak-Fedyuk, N.	01/06/1974	F			
16	Kovrigin Sergey		M	<input checked="" type="checkbox"/>		
17	Silenko Peter		M		<input checked="" type="checkbox"/>	A1

b. Did any of the participating students complete a thesis in whole or in part based on research directly related to the CRDF-sponsored project? Yes ☒ No ☐

c. If “Yes”, check all that apply: ☒ Doctoral/Candidat ☒ Undergraduate

2. Project-Related Travel

a. How many FSU team members traveled to the United States for project-related purposes during the term of the grant?	1
b. Of these, how many were students?	-
c. How many FSU team members traveled to countries other than the U.S. for project-related purposes such as presenting CGP research results at an international conference?	1
d. Of these, how many were students?	-
e. How many FSU team members left the FSU for six months or more during the grant period to take a position in a foreign laboratory or organization?	-
f. Of these, how many were students?	-

For all participants in Question "e" above, please provide the following information:

	Student?	Period of Time Abroad				Destination		
		< 1 year	1-2 years	> 2 years	Returned home	USA	Other FSU Country	Other (please specify)
Team member 1	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Team member 2	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Team member 3	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

3. Award Administration

a. Did you encounter any administrative difficulties during the course of the project? Yes ☒ No ☐

b. If "Yes", please identify the type of problem encountered by checking the appropriate box below (check all that apply).

- | | |
|--|--|
| <input type="checkbox"/> Individual financial support payments | <input type="checkbox"/> Travel /Visa Issues |
| <input checked="" type="checkbox"/> Purchase of materials & services | <input type="checkbox"/> Cost-share payments |
| <input type="checkbox"/> Institutional support payments | <input type="checkbox"/> Communication with CRDF staff |
| <input type="checkbox"/> Other (please describe) | |

c. Please comment on how these difficulties were addressed and/or resolved.

Renouncement for purchase of a notebook.

**Please purchase the Request at 26 May on Total amount 986\$ (see F300C with bank account attached file).
Please present me this very desirable necessary computer as a price for good work and as a advance for future FSTM CRDF project.**

4. CRDF Performance

On a scale of 1 to 5, rate the performance of CRDF staff in administering your award.

Poor

Good

Excellent

1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☒
Please provide any additional comments regarding CRDF's performance.

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SECTION V: Bibliography of Project-Related Publications

Award Number: UE2-2456

BIBLIOGRAPHY OF PROJECT-RELATED PUBLICATIONS

1. Pokropivny V.V. "Nanostructured superconductors : From granular through wire towards high- T_c nanotubular 2D composites". International Journal of Nanotechnology, V.1, N1, (2004) p.170-192 (Inderscience, USA).
 2. Chegel V.I., Poperenko L.V., Ozerov M.V., Pokropivny V.V. "Modification of plasmon resonance in gold film covered BN nanotubes" Proc. of Fifth Conf. "Problems of Optics & High Tech. Mat.Sci" (SPO 2004), (2004) p.168-169 (Ukraine).
 3. Pokropivny V.V., Pokropivny A.V. "Structure of "cubic graphite" - is the simple cubic fullerite C_{24} ". Physics of Solid State, v.46, No 2, (2004) p.392-394 (Russia).
 4. Pokropivny V.V., Bekenev V.L. "Electronic structure of novel carbon allotrope, the simple cubic fullerite SCF- C_{24} ("cubic graphite") as perspective low-dielectric molecular semiconductor". Fullerenes, nanotubes, and carbon nanostructures. Vol.13, No S1, (2005) p. 415-426 (Taylor,UK)
 5. Pokropivny V.V. "Structures of unconventional carbon allotrops and BN polymorphs". Nanostructured Materials Science.- 1, №1, (2005) p.39-56 (Ukraine).
- If you have not made any conference presentations, please check here and explain: ☐
- Are you planning on making any conference presentations in the near future? ☒
If so, please describe planned presentations and list the dates and locations of the respective conferences.
6. Pokropivny V.V., Bekenev V.L. "Electronic structure of novel carbon allotrope SCF- C_{24} , SCF- $B_{12}N_{12}$ ". Physics of Solid State (2005) (Russia).
 7. Pokropivny V.V., Bekenev V.L. "Electronic properties of novel boron nitride polymorphes , SCF- $B_{12}N_{12}$, SCF- $B_{24}N_{24}$, HDF- $B_{12}N_{12}$ ". Physics & Technique of Semiconductors (2005) (Russia).
 8. Pokropivny V.V. "Unique opportunity of photo-acousto-electronic super-resonance in nanotubes and their crystals" Journal of Materials Science & Engineering. C. (2005) (Elsevier, UK).
 9. Brodovoi A.V. , Bunchuk S.G., Pokropivny V.V., Skorokhod V.V. "Magnetic properties of nanoporous Si powder" International Journal of Nanotechnology. V3, N1/2 (2006) (Inderscience, USA).
 10. Pokropivny V.V. "Editorial Preface. Entering into Nanotechnology Era" International Journal of Nanotechnology. V3, N1/2 (2006) (Inderscience, USA).
 11. Pokropivny V.V., Kovrigin S., Gubanov V., Partch R. "Ab initio calculation of Raman and infra-red spectra of single-walled BN nanotubes" Physics of Solid State (2005) (Russia).
 12. Pokropivny V.V., Prilutsky E.V., Oleinik G.S., Lyachenko V.I., Gubanov V.I., Partch R. "Boron nitride covers on thin SiC whiskers". Powder metallurgy and Metal Ceramics (2006) (Ukraine).
 13. Pokropivny V.V., Smolyar A.S., Pokropivny A.V., Kuts V.A., Nesterenko Yu.V., Gubanov V.A., Brodovoi A.V., Partch R. " Fluid synthesis and structure of novel BN polymorph -

hyperdiamond fulborenite HDF- $B_{12}N_{12}$ (E-phase)" Nanostructured Materials Science.- 1, №1, (2005) (Ukraine).

CRDF COOPERATIVE GRANTS PROGRAM: FINAL PROJECT REPORT

SECTION VI: Conference Presentation List Award Number: UE2-2456

LIST OF PROJECT-RELATED CONFERENCE PRESENTATIONS

1. Pokropivny V.V. "Possibility of photo-acousto-electronic resonance in nanotubes and their crystals" (Poster Presentation) Abstracts of E-MRS Spring Meetings-2004, May 24-29, Strasbourg, France.
2. Pokropivny V. "Novel perspective materials based on noncarbon nanotubes and fulborenites" (Oral Presentation) Nanotechnology Conference and TraidShow Nanotech-2005, 8-12 May, 2005, Anaheim, CA, USA.
3. Pokropivny V.V., Smolyar A.S., Pokropivny A.V., Kuts V., Partch R. "Fluid synthesis and structure of novel boron nitride polymorph - hyperdiamond fulborenite HDF- $B_{12}N_{12}$ " (Poster Presentation) Applied Diamond Conference (Nanocarbon-2005), May 15-19, 2005, Argon National Laboratory, IL, USA .
4. Pokropivny V.V., Bekenev V.L. "Structure and electronic properties of novel unconventional carbon allotropes and BN polymorpe" (Poster Presentation) Applied Diamond Conference (Nanocarbon-2005), May 15-19, 2005, Argon National Laboratory, IL, USA .
5. Chegel V.I., Popereenko L.V., Ozerov M.V., Pokropivny V.V. "Modification of plasmon resonance in gold film covered BN nanotubes" (Poster Presentation) Applied Diamond Conference (Nanocarbon-2005), May 15-19, 2005, Argon National Laboratory, IL, USA .
6. Pokropivny V.V., Smolyar A.S., Pokropivny A.V., Kuts V., Partch R. "Supercritical fluid synthesis, atomic and electronic structure of novel BN polymorph - hyperdiamond fulborenite HDF- $B_{12}N_{12}$ (E-phase)" (Poster Presentation) Abstracts of E-MRS Spring Meetings-2005, Symp. M, 31 May-3 June, 2005, Strasbourg, France.
7. Pokropivny V.V., Prilutsky E.V., Lyachenko V.I., Oleinik G.S., Gubanov V.I., Partch R. "Cover of BN on thin SiC whiskers" (Poster Presentation) Abstracts of E-MRS Spring Meetings-2005, Symp. M, 31 May - 3 June, 2005, Strasbourg, France.
8. Pokropivny V.V., Smolyar A.S., Pokropivny A.V., Kuts V., Partch R. "Novel unconventional carbon allotropes and BN polymorphes. Synthesis, spectra, structure and electronic properties" (Poster Presentation) Molecular Crysral Engineering, 17-22 June, 2005, Helsinki, Finland.
9. Pokropivny V.V., Smolyar A.S., Pokropivny A.V., Kuts V., Partch R. "Novel unconventional carbon allotropes and BN polymorphes. Synthesis, spectra, structure and electronic properties". Abstracts of International Workshop of Fullerenes and Atomoc Clusters IWFAC-05", p.208, 27.06-01.07, 2005, St.Petersburg, Russia.
10. Pokropivny V.V., Kovrigin S., Gubanov V., Partch R. "Raman and infra-red spectra of BN nanotubes// Abstracts of International Workshop of Fullerenes and Atomoc Clusters IWFAC-05", p.208, 27.06 -01.07, 2005, St.Petersburg, Russia
 - Are you planning on making any conference presentations in the near future? ☒
If so, please describe planned presentations and list the dates and locations of the respective conferences.
11. Pokropivny V.V., Smolyar A.S., Pokropivny A.V., Kuts V., Partch R. "Novel BN polymorph - hyperdiamond fulborenite HDF- $B_{12}N_{12}$ (E-phase).Fluid synthesis, spectra, atomic and electronic structure" Abstracts of International Symposium of Boron and Boron materials ISBB-05", 21-26 Aug, 2005, Hamburg, Germany .

12. Pokropivny V.V., Kovrigin S., Gubanov V., Partch R. "Raman and infra-red spectra of BN nanotubes" Abstracts of International Symposium of Boron and Boron materials ISBB-05, 21-26 Aug, 2005, Hamburg, Germany .

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SECTION VII: SUPPLEMENTAL INFORMATION (optional)

Award Number: UE2-2456

CRDF appreciates receiving supplemental information, such as **photographs, publicity articles, publication copies, Power Point presentations, or other materials**. Please send such materials directly to the CRDF contacts listed in the General Instructions on page 2.

If you submit photographs, please be sure to identify all persons pictured and indicate their roles in the CRDF project. Please be aware that unless you indicate otherwise, CRDF reserves the right to use photographs and other materials above in publicly-distributed CRDF documents.

If you do not have any supplemental materials to submit, please check here: ☐



Photos made during visit of PI, Prof Richard Partch to Kiev team (From left to right): PI, Dr. V.Pokropivny, Prof. R. Partch, M.Sc. S. Kovrigin, Dr. A. Smolyar.